Global Advanced Research Journal of Agricultural Science (ISSN: 2315-5094) Vol. 8(8) pp. 265-270, September, 2019 Issue.
Available online http://garj.org/garjas/home
Copyright © 2019 Global Advanced Research Journals

Full Length Research Paper

Spatial Variability in Soil Properties and Plant Nutrient of Paddy Rice in Mwea, Kenya

Kundu C.A. [*1], [2]T. Masunaga, [2]K. Sato, [2]M. Ishii, [3]A.Yamauchi, [4]D. Makihara and [5]R.K. Wanjogu

[1]Kenya Agricultural and Livestock Research Organization (KALRO), Box 169-50100, Kakamega, Kenya
[2]Faculty of Life and Environmental Sciences, Shimane University, 1060 Nishikawatsu-cho, Matsue city, Shimane 690-8504 Japan
[3]Graduate School of Bioagricultural Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
[4]International Co-operation Centre for Agricultural Education (ICCAE), Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
[5]Mwea Irrigation Agricultural Development Centre (MIAD), Box 210-10303, Wang'uru, Kenya

Accepted 02 June, 2019

Lowlands constitute major environment for rice cultivation in Kenya, but declining soil productivity has led to low poor quality yields. This study assessed soil and yield quality of rice in Mwea irrigation scheme. Surface 0-15cm soil was sampled for laboratory analysis. Rice straw and grain was collected and analysed for total nutrient. Results obtained for soil and plant were evaluated basing on nutrient guidelines for rice. Results indicated that soil pH was moderately high and salt concentration negligible (< 0.4 dS/m). Soil total carbon was moderately high while total nitrogen was low. Available phosphorus, sulphur and silica all exceeded deficiency level for rice. Exchangeable Ca^{2+} and Mg^{2+} dominated compared to exchangeable K^+ and Na^+; and as a result severe K^+ deficiency because of cation imbalance existed. Among micronutrients, soil Fe, Mn and Cu were high while Zn was deficient. Grain yields were below optimum and plant analyses revealed deficiencies in straw total sulphur, K and Ca in some units. Grain samples showed deficiency in total Ca, Fe, K, Mg and S. Soil condition and nutrient concentrations affected nutrient accumulation in straw and grain. Appropriate soil management practices should be considered for improved quality and quantity of yields.

Keywords: Cation imbalance**,** lowlands**,** Mwea irrigation scheme, soil nutrient

INTRODUCTION

Low productivity of food crops because of little or no nutrient application in Sub-Saharan Africa (SSA) contributes to food insecurity (Shapouri *et al*., 2010). Although mineral fertilizers are widely used globally, their use remains low (IFDC, 2006). The fertilizer is not targeted to specific crop, soil and agro-ecological conditions and application rates are 'blanket' (Giller *et al*., 2011). Importance of rice has increased in SSA (Seck *et al*.,

*Corresponding Author's Email: carolinekundu@gmail.com

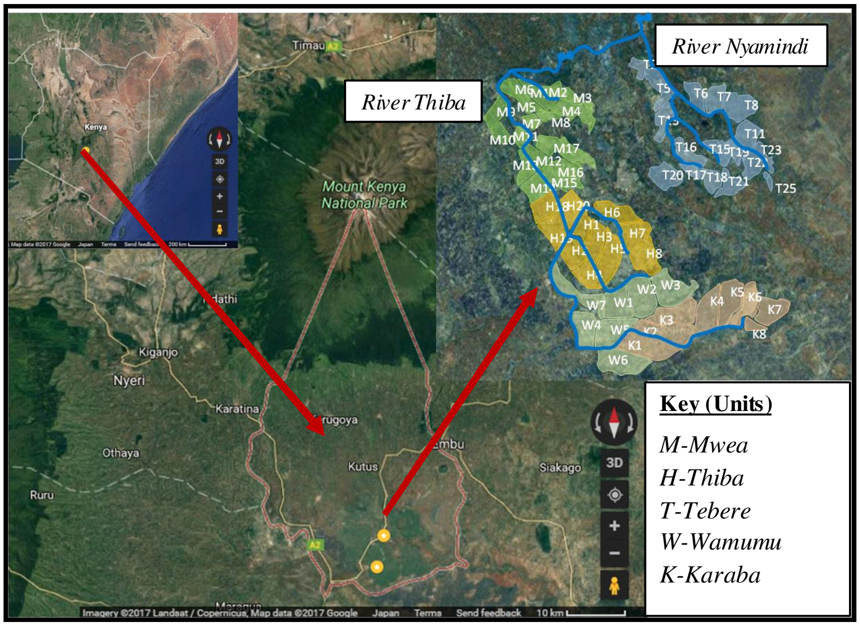

Figure 1: Location and layout of Mwea Irrigation Scheme

2010). In Kenya, demand exceeds production and the gap is filled through huge and costly imports. Current production meets 20% of total demand and consumption projected to rise with increasing population and changes in eating habits (Atera *et al*., 2011). To attain self-sufficiency, total domestic production must increase at 9.3% per annum (Ministry of Agriculture, 2008). Stakeholders must understand impediments that exist along rice value chain and import process and explore opportunities to benefit all (Atera *et al*., 2018).

Plant growth and development is reliant on nutrient from soil and nutrients present in tissues is dependent on demand and soil availability (Marschner, 2012). Humans require nutrients obtained from daily diets. Unfortunately, majority of plant derived food contains low bioavailable nutrients. Current high yielding white rice though a major staple food and energy source is poor in essential micronutrients such as Zn (Sharma *et al*., 2013).

Variability in soil and yield exist which may lead to site-specific management (Shoji *et al*., 2005). Grain quality after yield is important for rice production and nutritional quality is considered as one of the main objectives for rice improvement (Ning *et al*., 2009).

In Kenya's rice production systems, fertilization is restricted to N and P (Kihoro *et al*., 2013) and relationship between soil minerals and grain quality has not received any attention. This work aimed at analysing soil nutrient supplying power and its effect on nutrient accumulation in Kenya's irrigated rice system.

MATERIALS AND METHODS

Mwea irrigation scheme is located on lower slopes of Mt. Kenya in Central Kenya (Figure 1). Total area is 12,282ha with about 9,000ha under rice production. It is divided into five units; Mwea, Thiba, Wamumu, Karaba and Tebere located at different topographical elevation. The scheme gets water from two rivers; Nyamindi; serving Tebere and Thiba serving Mwea, Thiba, Wamumu and Karaba (Figure 1).

Surface 0-15cm soil was collected from benchmarked farms and analysed for pH, electrical conductivity (EC), total carbon (TC), total nitrogen (TN), available silica (SiO_2), available sulphur (S), available phosphorus (P_2O_5), available micronutrients and exchangeable cations using standard procedures.

At harvesting, straw and grain samples were collected from the same fields and analysed for total elements. They were digested in HNO_3 according to Koyama and Sutoh, (1987) and concentrations determined by Inductively Coupled Plasma-Atomic Spectroscopy (ICPE-9000, Shimadzu).

Statistical Analysis

Data were subjected to analysis of variance using R software version 3.4.0 for windows and statistically significant differences between means compared at 5% level using Duncan Multiple range test. Soil and plant nutrient concentrations were evaluated basing on guidelines for rice.

Table 1: Soil chemical properties

		Unit				
Parameter	Deficiency level*	Mwea	Thiba	Wamumu	Karaba	Tebere
pH		6.2	6.2	6.9	6.9	7.0
EC(dS/m)	<4	0.12	0.17	0.17	0.23	0.18
TN(g/kg)		1.30	1.20	0.90	0.87	1.43
TC(g/kg)		20.1	18.9	16.2	15.6	24.0
Avail. S(mg/kg)	9	48.2	51.5	60.0	90.1	78.7
Avail. P_2O_5(mg/kg)	12-20	87.0	123	50.0	36.4	152
Avail. SiO_2(mg/kg)	86	425	429	507	498	608
Exchangeable cations($cmol_c$/kg)						
Ca^{2+}	1	33.0	41.7	47.2	51.7	36.9
Mg^{2+}	1	20.6	21.7	24.4	35.4	21.2
K^+	0.2	0.08	0.12	0.36	0.40	0.56
(Ca +Mg)/K ratio	100	625	533	240	226	150
Available micronutrients(mg/kg)						
Fe	4-5	134.0	94.8	69.4	68.5	90.9
Mn	3-30	72.9	198.0	136.0	112.0	94.7
Cu	0.1	2.10	1.14	4.77	5.64	2.90
Zn	2	0.22	0.26	0.55	0.62	0.63

**Dobermann and Fairhust, 2000.*

RESULTS AND DISCUSSIONS

Soil Properties

Mean values for soil properties are presented in Table 1. Soil pH is a driver of soil fertility because it influences availability and uptake of nutrients and toxins (Brady and Weil, 2014). Soil pH increased down the elevation from Mwea to Karaba (Table 1). This high soil pH is attributed to basaltic parent material and dry climate as reported in earlier studies (Kondo *et al*., 2001). Values of 5.5 to 7.0 are appropriate for provision of nutrients in grain and vegetable crops (Brady and Weil, 2014) therefore values observed are appropriate.

EC was low and increased down the elevation thus considered non-saline. Results revealed low TN and moderate TC that decreased down elevation (Table 1). N supply limits grain yield and demand for other macronutrients in rice (Dobermann *et al*., 1998). Moderate soil TC observed could be due to stubble and low TN because of low rates and improper application methods that lead to N losses despite widespread use of N fertilizers. Effluents from rice fields indicated high nitrates (>5mg/l) according to Onderi, (2016), an indication of N loss in irrigation water. A common practice of residue removal (Kondo *et al*., 2001) exacerbates N loss.

Available P_2O_5, S, SiO_2, Fe, Mn and Cu exceeded deficiency level. High S concentration observed is attributed to widespread use of ammonium sulphate fertilizers (Kihoro *et al*., 2013). Studies on clays by Muriithi *et al*., (2012) indicated 42-50% silica, thus high SiO_2 content.

Exchangeable Ca^{2+} and Mg^{2+} dominated and exceeded deficiency level while K^+ was deficient in Mwea and Thiba (Table 1). Cations increased down the elevation due to accumulation in lower depression area. Cation imbalance was evident and severe in Mwea and Thiba. K fertilizers are seldom used, and straw removal exacerbates K deficiency. Zn was below deficiency level because micronutrient fertilizers are hardly used and thus need to introduce Zn-based fertilizers.

Straw and Grain yield

Straw and grain yield ranged from 2.4 to 8.7t/ha and 3.3 to 8.2t/ha respectively. Mean values for straw and grain yield are shown in Table 2.

Yields decreased down the elevation with higher yields observed in Thiba unit and lowest in Karaba (Table 2). Grain yield was lower than potential yield of 10t/ha according to Ministry of Agriculture, (2008).

Table 2: Mean straw and grain yield

Unit	Straw(t/ha)	Grain(t/ha)
Mwea	5.0^{ab}	5.8^{ab}
Thiba	6.2^{a}	6.8^{a}
Wamumu	5.1^{ab}	5.6^{ab}
Karaba	4.4^{b}	5.0^{b}
Tebere	5.4^{ab}	5.6^{ab}
Overall mean	5.1	5.6

Means followed by the same superscript letter in a column are not significant at 5% level

Table 3: Mean straw total nutrient concentration

Total nutrient(%)	Deficiency level*	Mwea	Thiba	Wamumu	Karaba	Tebere
Zn	0.0030	0.0059^{a}	0.0042^{b}	0.0052^{ab}	0.0044^{ab}	0.0045^{ab}
Cu	0.0003	0.0024^{a}	0.0022^{a}	0.0026^{a}	0.0019^{b}	0.0012^{b}
Fe	0.0350	0.1045^{a}	0.0581^{a}	0.1509^{a}	0.0967^{a}	0.1303^{a}
Mn	0.0450	0.0590^{b}	0.0926^{ab}	0.0869^{ab}	0.0802^{b}	0.0822^{a}
P_2O_5	0.1000	0.3303^{a}	0.2448^{a}	0.3092^{a}	0.2139^{a}	0.2416^{a}
S	0.0750	0.0696^{b}	0.0864^{b}	0.0857^{b}	0.0840^{b}	0.0896^{a}
K	1.4000	0.6619^{c}	0.6858^{c}	1.4574^{ab}	1.5985^{bc}	1.6725^{a}
Mg	0.2000	0.2687^{ab}	0.2280^{b}	0.2729^{ab}	0.2850^{b}	0.3028^{a}
Ca	0.3000	0.2793^{a}	0.2511^{a}	0.3266^{a}	0.3828^{a}	0.3244^{a}

Dobermann and Fairhurst (2000)

Means followed by the same letter in a row are not significantly different at 5% level

Straw and grain nutrient content

Average total straw and grain nutrient contents are shown in Tables 3 and 4 respectively with deficiency level according to Dobermann and Fairhurst, (2000).

For nutrients to accumulate in straw, they are taken from soil through transpiration stream (Sperotto, 2013). This depends on nutrient availability, soil condition and plant factors. Most nutrients exceeded deficiency level in straw except for total S in Mwea and total K and Ca in Mwea and Thiba (Table 3). Positive associations between soil and straw nutrient accumulations were observed except Zn which showed high straw accumulation despite being deficient in soil.

Accumulation in edible parts occurs through redistribution of accumulated nutrients or continuous soil uptake. Phloem transport from old to new leaves is involved and depends on element mobility (Sperotto, 2013). Grain total Cu, Mn, P_2O_5 and Zn exceeded deficiency level while total Ca, Fe, K, Mg and S were deficient (Table 4).

Remobilization moves nutrients to developing seeds provided senescence and seed import are synchronized to provide source-sink relationships (Waters and Sankaran, 2011).

High grain phosphorus could have come from continuous soil uptake and remobilization. Sulphur is less mobile and its deficiency reduces grain yield and quality by 10-40% without visible symptoms (Khurana *et al.,* 1999). Pot experiments revealed S deficiency indicated by N:S ratios of 16 and 25 significantly affect grain quality (Randall *et al*., 2003). Enhancing N nutrition to reduce N:S ratio could help improve S accumulation in grain. Increased S application after anthesis enhanced its accumulation in grain (Randall *et al*., 2003), thus need to properly time S application.

Low grain Mg (<0.15%) could be attributed to binding by phytic acid known chelate metal cations (Raboy, 2009). Unbalanced crop fertilization with N:P:K reduces Mg in seeds (Guo *et al.,* 2016), thus balanced crop nutrition should be considered. Grain total K was below deficiency level because of cation imbalance that negated its uptake and accumulation. Since K, Mg and P accumulate in the aleurone layer (Ogawa *et al*.,, 1979), it is likely that phytic acid complexes them.

Grain Zn was high because it is loosely bound and localized in aleurone layer and inner endosperm thus not masked by phytic acid. Similarly, Cu passes the aleurone layer without being captured by phytic acid (Iwai *et al*., 2012). Prolonged submerged conditions, low soil Zn and N negate Fe uptake and accumulation.

Table 4: Mean grain total nutrient concentration

Total nutrient(%)	Deficiency level*	Mwea	Thiba	Wamumu	Karaba	Tebere
Zn	0.0020	0.0050^{a}	0.0044^{b}	0.0045^{b}	0.0046^{ab}	0.0044^{b}
Cu	0.0010	0.0017^{ab}	0.0016^{ab}	0.0019^{a}	0.0013^{b}	0.0018^{ab}
Fe	0.0250	0.0085^{a}	0.0086^{a}	0.0097^{a}	0.0134^{a}	0.0119^{a}
Mn	0.0050	0.0083^{b}	0.0112^{a}	0.0092^{ab}	0.0080^{b}	0.0086^{ab}
P_2O_5	0.2000	0.6915^{a}	0.6133^{b}	0.6475^{b}	0.6347^{b}	0.6454^{b}
S	0.1000	0.0751^{b}	0.0731^{b}	0.0734^{b}	0.0729^{b}	0.0790^{a}
K	0.2900	0.1844^{abc}	0.1705^{c}	0.1901^{ab}	0.1755^{bc}	0.1977^{a}
Mg	0.1500	0.1285^{a}	0.1182^{b}	0.1219^{b}	0.1192^{b}	0.1220^{b}
Ca	0.0500	0.0393^{a}	0.0385^{a}	0.0395^{a}	0.0369^{a}	0.0342^{a}

Dobermann and Fairhurst (2000)
Means followed by the same letter in a row are not significantly different at 5% level

According to Shi *et al*., (2012), N nutrition showed positive effect on Fe and Zn translocation. Additional and timely N supply in wheat enhanced grain Fe and Zn (Slamet-Loedin *et al*., 2015) because of increased protein and sink strength. Therefore timely and appropriate N nutrition should be considered to enhance grain Fe and Zn. In Wang *et al*., (2014), Zn fertilization with alternative wet and drying decreased phytic acid and increased yield. Further research into this aspect is necessary to elucidate this on Mwea soils and Kenyan rice varieties.

CONCLUSIONS

Spatial variability in soil properties plays a role in modeling and natural resource management. Soil results indicated high nutrient supplying power with deficiencies in N, Zn and K nutrient status. Reasonable grain yields were obtained but of poor quality.

RECOMMENDATIONS

An improvement in limiting nutrients like N, Zn and K at appropriate time could help avert the negative effects reflected in grain yield and quality. Appropriate field practices like mid-season drainage could also help in nutrient availability and uptake.

ACKNOWLEDGEMENT

We are indebted to JST and JICA for funding through SATREPS. Many thanks to rice farmers in Mwea, entire KALRO and MIAD.

REFERENCES

Atera EA, Onyancha FN, Majiwa EBO (2018). Production and Marketing of Rice in Kenya: Challenges and Opportunities. *Journal of Development and Agricultural Economics*. 10(3):64-70

Atera EA, Onyango JC, Azuma T, Asanuma S, Itoh K (2011). Field evaluation of selected NERICA rice cultivars in western Kenya. *African Journal of Agricultural Research*. 6(1):60-66

Brady NC, Weil RR (2014). The Nature and Properties of Soils, 14th Edition, Pearson Education Limited.

Dobermann A, Cassman KG, Mamaril CP, Sheehy JE (1998). Management of phosphorus, potassium and sulphur in intensive, irrigated lowland rice. *Field Crops Research*. 56, 113-138.

Dobermann A, Fairhurst T (2000). Rice: Nutrient disorders & nutrient management Manila, Philippines: Potash & Phosphate Institute and International Rice Research Institute. pp 192.

Gao X, Brown KR, Racz GJ, Grant CA (2010). Concentration of cadmium in durum wheat as affected by time, source and placement of nitrogen fertilization under reduced and conventional-tillage management *Plant Soil*, 337, 341-354.

Giller KE, Tittonell P, Rufino MC (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*. 104, 191-203.

Guo W, Nazim H, Liang Z, Yang D (2016). Magnesium deficiency in plants: An urgent problem. *The crop Journal*. 4, 83-91.

International Fertilizer Development Center (IFDC). (2006). *Africa Fertilizer Summit Proceedings*, Abuja, Nigeria.

Iwai T, Takahashi M, Oda K, Terada Y, Yoshida KT (2012). Dynamic changes in the distribution of minerals in relation to phytic acid accumulation during rice seed development. *Plant Physiology*. 160, 2007-2014.

Khurana N, Gupta J, Chatterjee (1999). Sulphur deficiency influences metabolism and grain quality of Rice. *Indian Journal of Plant Physiology*. 4, 277-281.

Kihoro J, Njoroge JB, Murage H, Ateka E, Makihara D (2013). Investigating the impact of rice blast disease on the livelihood of the local farmers in greater Mwea region of Kenya. *SpringerPlus*. 2, 308-320.

Kondo M., Toshinari O.T.A. and Wanjogu R. (2001). Physical and chemical properties of Vertisols and soil nutrient management for intensive rice cultivation in the Mwea area in Kenya. *Japanese Journal of Tropical Agriculture*. 45, 126-132.

Koyama T, Sutoh M (1987). Simultaneous multi-element determination of soils, plant and animal samples by inductively coupled plasma emission spectrometry. *Japanese Journal of Soil Science and Plant Nutrition*. 58,578-585 (In Japanese).

Kyuma K (2004). *Paddy soil science*, Kyoto University Press. pp 297

Marschner P (ed.) (2012). Marschner's mineral nutrition of higher plants, 3rd Ed. Academic Press, San Diego, CA, USA

Ministry of Agriculture (2008). National Rice Development Strategy (2008 – 2018). Agricultural Information Resource Centre, Nairobi, Kenya.

Muriithi NT, Karoki KB, Gachanja AN (2012). Chemical and Mineral Analyses of Mwea clays. *International Journal of Physical Sciences*. 7, 5865-5869.

Newell-McGloughlin M, 2008. Nutritionally improved agricultural crops *Plant Physiology,* 147, 939-953

Ning HF, Liu ZH, Wang QS, Lin ZM, Chen SJ, Li GH, Wang SH, Ding YF (2009). Effect of nitrogen application on grain phytic acid and protein concentrations in japonica rice and its variations with genotypes. *Journal of Cereal Science.* 50, 49-55.

Ogawa M, Tanaka K, Kasai Z (1979). Accumulation of phosphorus, magnesium and potassium in developing rice grains: followed by electron microprobe X-ray analysis focusing on the aleurone layer. *Plant and Cell Physiology*. 20, 19–27.

Onderi JN (2016). Suitability Assessment of Effluents from Mwea Irrigation Scheme for reuse in Irrigation for Rice Production, Kirinyaga County, Kenya. Unpublished MSc Thesis, Kenyatta University.

Raboy V (2009). Approaches and challenges to engineering seed phytate and total phosphorus. *Plant Sciences.*177, 281-296.

Randall PJ, Freney JR, Spenser K (2003). Diagnosing sulfur deficiency in rice by grain analysis. *Nutrient Cycling in Agroecosystems.* 65, 211-219.

Seck PA, Tollens E, Wopereis MC, Diagne A, Bamba I (2010). Rising trends and variability of rice prices: Threats and opportunities for sub-Saharan Africa. *Food Policy*. 35, 403-411.

Shapouri S, Rosen S, Peters M, Baquedano F, Allen S (2010). Food security assessment. 2010-20, DIANE Publishing.

Sharma A, Patni B, Shankhdhar D, Shankhdhar SC (2013). Zinc-An Indispensable Micronutrient. *Physiology and Molecular Biology of Plants*, 19, 11-20.

Shi RL, Weber G, Köster J, Reza-Hajirezaei M, Zou C, Zhang F, von Wirén N (2012). Senescence-induced iron mobilization in source leaves of barley (*Hordeum vulgare*) plants. *New Phytologist*. 195, 372-383.

Shoji K, Kawamura T, Horio H (2005). Variability of micro-elevation, yield and protein content within a transplanted paddy field. *Precision Agriculture*. 6, 73–86.

Slamet-Loedin IH, Johnson-Beebout SE, Impa S, Tsakirpaloglou N (2015). Enriching rice with Zn and Fe while minimizing Cd risk. *Frontiers in Plant Science.* 6, 121.

Sperotto RA (2013). Zn/Fe remobilization from vegetative tissues to rice seeds: should I stay or should I go? Ask Zn/Fe supply! *Frontiers in Plant Science*. 4, 464.

Wang YY, Wei YY, Dong LX, Lu LL, Feng Y, Zhang J, Pan FS, Yang XE (2014). Improved yield and Zn accumulation for rice grain by Zn fertilization and optimized water management. *Journal of Zhejiang University- Science B (Biomedicine & Biotechnology)*, 15(4): 365-374.

Waters BM, Sankaran RP (2011). Moving micronutrients from the soil to the seeds: Genes and physiological processes from biofortification perspective. *Plant Science.* 180, 562-574.